Stacked Rapid Sand Filtration Summer 2010 Reflection Report 2

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Primary Author:

Jonny Ayala

Anderson Cordero

Michael Liu

Sarah Stodter

Primary Editor: Sarah Stodter

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Cornell University

School of Civil & Environmental Engineering

Ithaca, NY 14853-3501

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Abstract

The objective of the Stacked Filtration team is to design and build a vertically stacked filtration system that meets the AguaClara project constrains.

In the previous semester, the Stacked Filtration Team conducted research on stacked filtration and rapid sand systems, completed a literature review of past research and technology, and developed a robust laboratory filtration system. Most recently, we were able to successfully back wash the system by sequentially fluidizing individual sand layers. Our main challenge for the future is to add pressure sensors to the experimental set up to indicate when back washing is necessary, and to install a clear PVC pipe to visually confirm flow patterns and fluidization levels within the filter.

Introduction

The task of Filtration Team is to design a filtration system for the AguaClara water treatment plants already operating. The filtration system must be able reduce the turbidity of current AguaClara effluent water ranging from 5-10 NTU to a turbidity of less than 1 NTU. The system must not require electricity, try to avoid specialized components that would be difficult to obtain in remote areas, and should be easy and economically efficient to construct and maintain.

The work of the previous semester consisted on creating an appropriate stacked filtration experiment design and researching past sand filtration methods and technology. They designed a filtration system where the sand layers are stacked on top of one another. This way the same water would be used to back wash all of the filters. The design entails four filters stacked on top of each other, thus four layers of sand with 20 cm of depth each. Three slotted influent pipes and two slotted effluent pipes will be placed in 4" inner diameter PVC pipe.

Currently, we have built a bench-scale stacked rapid sand filter apparatus and have started to take turbidity readings. We have come across a new challenge of overcoming the high pressure in the influent water line were the alum dose (1.5 mg/L) and clay need to be pumped. We have moved these inlets to a location of lower pressure. Most recently, we have had trouble achieving consistent raw water turbidity due to clay settling in the clay stock line.

Experimental Design

We conducted our experiments by measuring the effluent and the influent turbidity of clean tap water with a controlled dose of clay. From there we analyze the collected information with MathCAD. We have tried to control the clay dosing to turn the water into 5 NTU and 10 NTU however we have had trouble getting the influent water to those turbidities and have been testing with water with turbidity revolving around 8 NTU. So far our rapid filter has been extremely efficient at removing turbidity from water. With influent water turbidity around 8 NTU we have managed to reduce the turbidity to below US standards. Backwashing the filter has also gone smoothly and proven effective at removing clay from the filter.

Many changes that were made to the experiment revolved around fixing a problem that had occurred during the experiments set up and construction stages. One of the most prominent problems in our experiment is clay settling out in the tubes. We have tried to remedy this by decreasing the clay concentration of the clay stock and increase the flow rate. We have also tried to decrease the diameter of the tubing used for the clay stock.

From what we have seen, the rapid sand filter has done an excellent job at lowering turbidity of water. In the future we look to refining our research such as researching and experimenting with depth of the filters and different diameters of sand. We also need to have a calculated time with how long it takes the filter to completely backwash.

Results and Discussion

After confirming that back washing the filter is in fact possible, we proceeded to set up the filter to run full length trials. The experimental conditions used in all of the trials involved a filter flow rate of 2.7 L/min, which is equivalent to 5.6 mm/s total filtration velocity, with 1.4 mm/s per filter layer. We had an alum stock which delivered 1.5 mg/L alum to the raw water supply line, and a clay stock that was calibrated to deliver 5 NTU raw water. The first experiment we ran, we had issues with inconsistent influent turbidity since clay was settling out in the tubing, and we also ran out of alum. However, the results we achieved were very promising! As can be seen in Figure 1, the first experiment consistently achieved a pC* of more than 1, until the alum stock ran out. As shown in Figure 2, the resulting effluent turbidity was less than 0.2 NTU for this time period, about 12 hours.

Figure 1. Experiment 1: pC* vs Time. Filter flowrate: 2.7 L/min (5.6mm/s total, 1.4mm/s per filter layer). Note: Alum suspected to have run out at ~$5x10^4$ sec where performance drops.

Figure 2. Experiment 1: Turbidity vs Time. Filter flowrate: 2.7 L/min (5.6mm/s total, 1.4mm/s per filter layer). Note: Alum suspected to have run out at ~$5x10^4$ sec where performance drops.

The next experiment we ran, we replaced the clay and alum stocks with larger tanks so they would not run out over night, and also replaced the clay stock tubing in hopes that clay would not settle out in the line. The peristaltic pump tubing was not replaced due to the necessity of clamps which could only fit on size 16 tubing. As a result, we still had a problem with settling which resulted in increased raw water turbidity over time. In addition, there was a leak that forced us to turn off the experiment after only (15 hours). The results are nonetheless interesting. As shown in Figure 3, the pC* is above 1.5 after $2x10^{4}$ seconds. It is not clear what the dips in performance are a result of. It is possible that some sand grains are being pushed through the slotted pipes and into the effluent. As illustrated by Figure 4, the effluent turbidity for this experimental trial is below the US EPA standard of .3 NTU for the duration of the experiment, after a ripening time of ~$7x10^{3}$ seconds (2 hours).

Figure 3. Experiment 2: pC* vs Time. Filter flowrate: 2.7 L/min (5.6mm/s total)

Figure 4. Experiment 2: Effluent Turbidity vs Time. Filter flowrate: 2.7 L/min (5.6mm/s total)

It is necessary to discover the effective run time for this filter design, so we ran another experiment which we planned to let run until performance dropped, or the head loss became too great. In this third experimental trial, we used the same raw water conditions and filtration flow rate as described above. As shown in Figure 5, the stacked filtration design again achieves a pC* of 1.5. The sudden drop in performance is the result of a clay stock failure, where clay was not being added into the filter for a period of time. This can be seen in Figure 6 as well. After about 1.25×10^{5} seconds, the filter pC* drops dramatically. As indicated in Figure 6, the ripening time until the filter is achieving US EPA standards of .3 NTU for this experimental trial is only about 3600 seconds, which is half of that shown in the previous experiment. In addition, it is very clear where a drop in performance occurred, at approximately 1.2×10^{5} seconds (32 hours).

Figure 5. Experiment 3: pC* vs Time. Filter flowrate: 2.7 L/min (5.6mm/s total)

Figure 6. Experiment 3: Turbidity vs Time. Filter flowrate: 2.7 L/min (5.6mm/s total)

These results seem very promising and indicate that stacked filtration is in fact a feasible alternative to conventional rapid sand filtration. In future experiments, the size 16 peristaltic pump tubing for the clay stock will be replaced with size 13 tubing to reduce settling, as we have found pressure in the tap water line is no longer a problem. This will yield more consistent raw water turbidity readings.

Future Work

In following two weeks we aim to replace the vertical 4” diameter PVC pipe with a clear PVC pipe, which serves as the filtration unit. By doing so, visual confirmation will be possible. We want to be able to see whether the influent flow through the slotted pipes is uniform (via a dye test), and to confirm that complete sequential fluidization of each of the sand beds is achieved during back washing. In addition, we would like to visually confirm that 30% sand bed expansion is occurring, and what flow rate is required to do this. We will also add pressure sensors to the influent and effluent lines of the filter in order to tell when the particle build up in the filter is too great, and must be cleaned.

We will also conduct a performance comparison to a conventional single layer filter system of the same depth as an individual layer of our stacked filtration system (20 cm).

Team Reflections

Overall, the last two weeks have been very successful. There were three main problems we ran into and we were able to resolve them all quite nicely. First of all, much of the tubing we were using between the pumps and the inlet of the source water were blowing off due to the high pressure of the source water. So we were left to figure out how to reduce the pressure of the source water at the points of clay and alum dosing. To do this we decided to add the clay and alum after the water had flown through the valves and pressure regulators, where the pressure was much lower and easier to overcome. This facilitated the inflow of clay and alum and drastically reduced the chance of the tubes blowing off. Secondly, we were having some trouble pumping the clay stock into the source water without having it settle out in the connector tubes. In order to fix this we switched from size 16 to size 13 tubing between the pump and the source water inlet, making the tube equal in size to the one between the stock tank and the pump. This reduction in area increased the velocity of the clay stock between the pump and the source water inlet and minimized the probability of it settling out. We also switched the clay stock from its constant flow rate peristaltic pump to the variable flow rate pump that had been used by the alum stock, and vice versa. We did this because over time more and more clay was being added into the source water and increasing its turbidity. By using the variable flow rate pump we can now periodically lower the flow rate of the clay stock and keep the amounts of clay added to the system constant. Lastly, in order to validate our experimental results, we needed the experiments to last longer. We did this by switching to larger stock tanks which enabled us to use lesser concentrations and run the experiments for longer periods of time.